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ON THE THERMAL LAG IN THE OCEAN DURING A PERIOD OF CLIMATIC CHANGE

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Ocean-Atmosphere Research Institute

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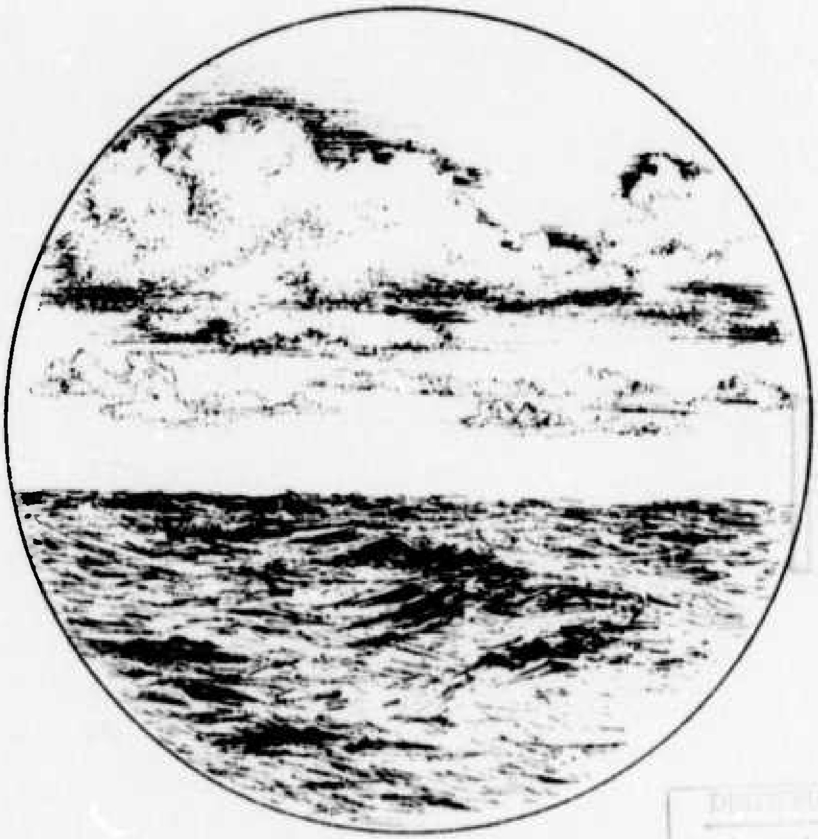

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On the Thermal Lag in the Ocean during a Period of Climatic Change

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A. Introduction.

As can be seen from the extensive literature on past climates and their changes, a great deal of study and thought has been devoted to this problem.

Whether we look to predictive theories of the general circulation to provide a solution of this problem or seek its solution from a study of the changes in the past by discovering their orderly sequence, or trace a connection between them and solar variability, volcanicity, and other possible causes, there is the need for establishing as accurately as possible the climates of the past both on land and in the sea, and their spatial and physical coherence along with a need for defining the special characteristics of the climatic elements that distinguish one from another.

One such characteristic of a major climatic element we wish to investigate is the response of the ocean as compared with the atmosphere during a period of climatic change.

The difference in the thermal and dynamic characteristics between the ocean as represented by sea surface temperatures, ocean currents, and sea ice cover (in the higher latitudes) on the one hand, and the atmosphere, as represented by air temperature and winds on the other, leads us to expect a slower and hence later response of the ocean during a period of climatic change than in the atmosphere. The following is an analysis of a possible time-lag of the response of the ocean vis a vis the atmosphere from a consideration of the sea surface temperatures in the northern No. Atlantic and Western Mediterranean, the sea temperature in the layer 0-200 m along the Kola (70°E) meridian, the sea surface temperatures from 8 Ocean Weather Stations in different locations in the No. Atlantic, the ice off Iceland, and finally, the pressure distribution (atmospheric circulation or winds) and air temperatures during the period 1921-1970 that was characterized by a rise, then a fall in temperature.

B. Analysis.

Mitchell (1961, 1963), following Willett (1950), has shown that beginning with the 1940's, the average "world" air temperature has taken a downward turn while remaining well above the long-term average. The change from the 1940-9 to the 1950-9 decades came, he found, to -0.19°C for the year as a whole, and to -0.25°C for the winter season.

Similarly, Rodewald in a series of papers (1963, 1967, 1972a, 1972b) treated in detail the sea surface temperatures in the northern No. Atlantic observed at the OWS ships which he compared with the air temperatures and the pressure distribution, his latest results showing a marked decrease in the air and sea temperatures in the No. Atlantic-Arctic in the most recent decade, 1961-70, as compared with that which preceded it. Earlier Smed has shown (1949) an increase in the sea surface temperature in the northern No. Atlantic between 50° and $66^{\circ}N$, approximately, that was especially marked in the 1930's.

1. Pressure Distribution.

For evidence about the changes in circulation and winds during the 1921-70 period, we have compared the pressure over the northern No. Atlantic, Greenland, and Europe during the 1921-50 period with that in the 1951-60 decade and next, the pressures in this decade with those in the 1961-70 decade.

Figure 1 shows an area of excess pressure over Greenland and the vicinity in the 1951-60 decade over the 1921-50 period, suggesting an increased outflow of cold air southward from Greenland and lower air temperatures over East Greenland, Iceland, northwestern Europe and the North Atlantic in this decade (Fig. 2).

Similarly, the area of excess of pressure in the 1961-70 decade over the 1951-60 decade extending eastward from Greenland to Scandinavia and beyond (Fig. 3) signifies a greater outflow of cold air from the Arctic in this decade (1961-70) than in the preceding one as is shown by the lower air temperatures (Fig. 4). Also, the area of negative air temperature differences is larger.

2. Sea Temperatures.

a. Northern No. Atlantic Areas A-N.

For analysis of possible trends in the sea surface temperatures of the northern No. Atlantic, we have made use of the mean monthly tabulations of deviations of sea surface temperature north of $50^{\circ}N$ in areas A to N, as designated by Smed (1949-1970), limiting ourselves to the April-September values for which more information is available than for the other months. The results obtained from the comparison of the temperatures in the 1951-60

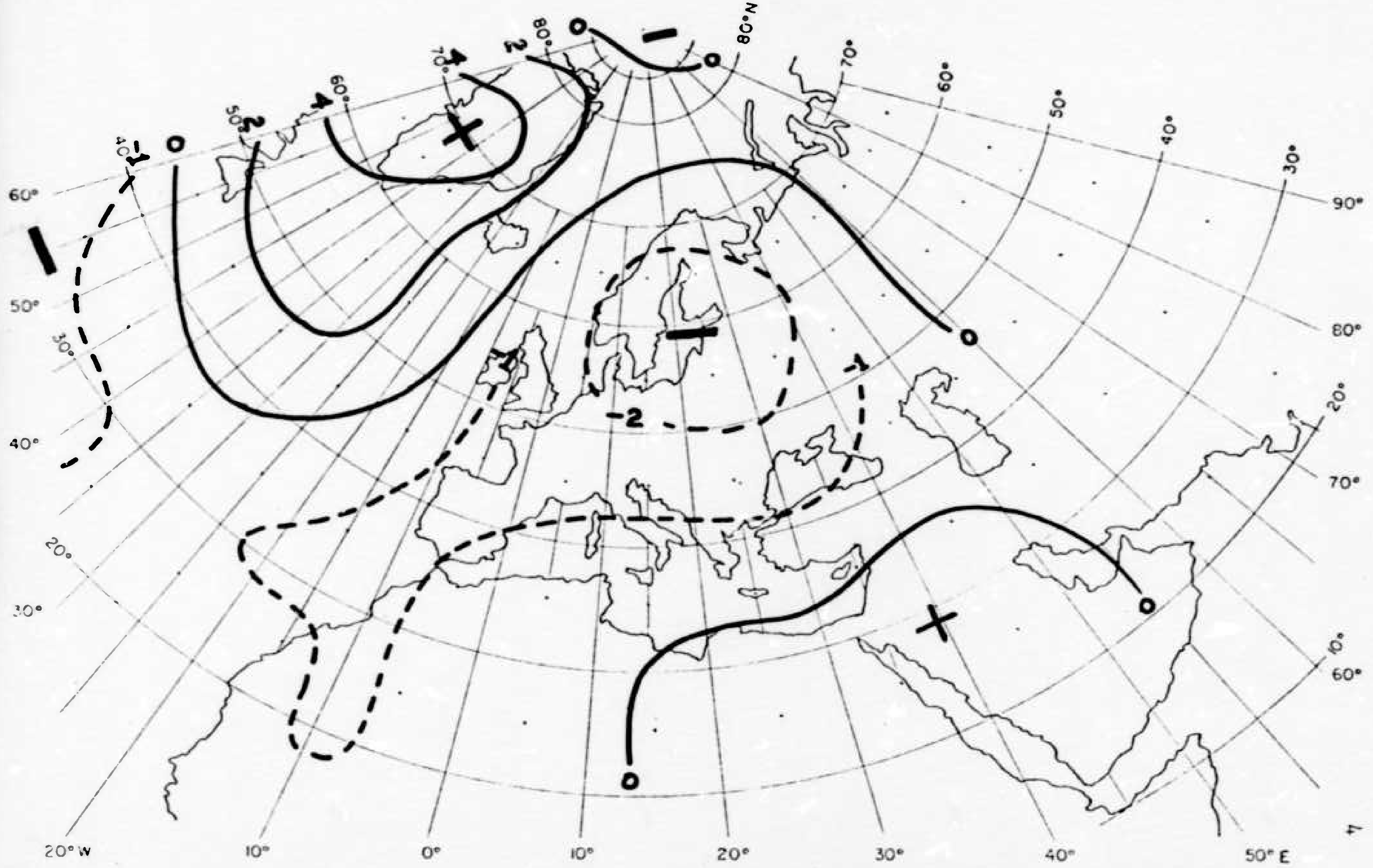

Figure 1. Difference (1950/1-1959/60 minus 1920/1-1949/50) December-February Pressure (mb).

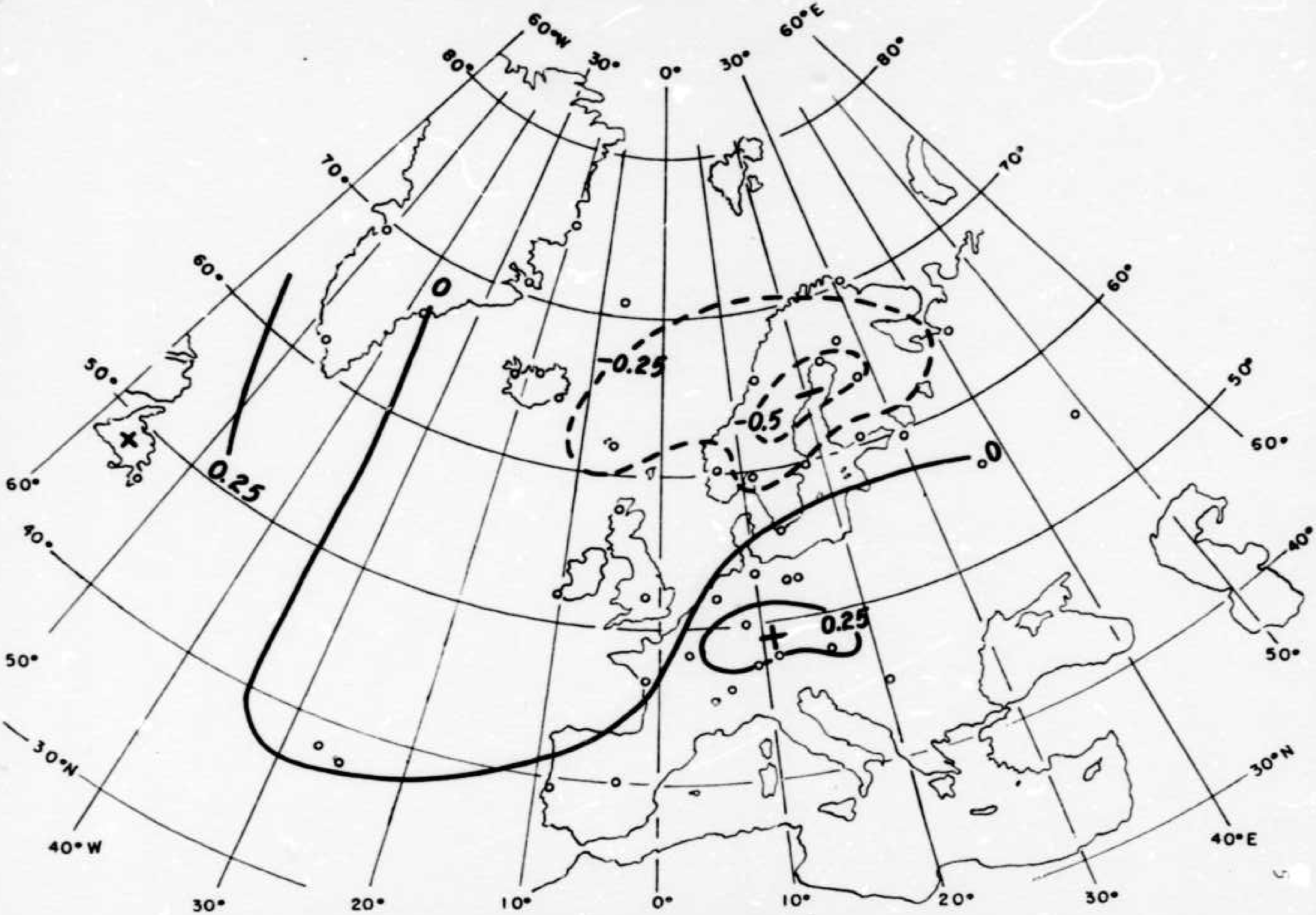

Figure 2. Differences (1951-1960 minus 1921-1950) mean annual air temperatures (°C). Circles denote locations of stations.

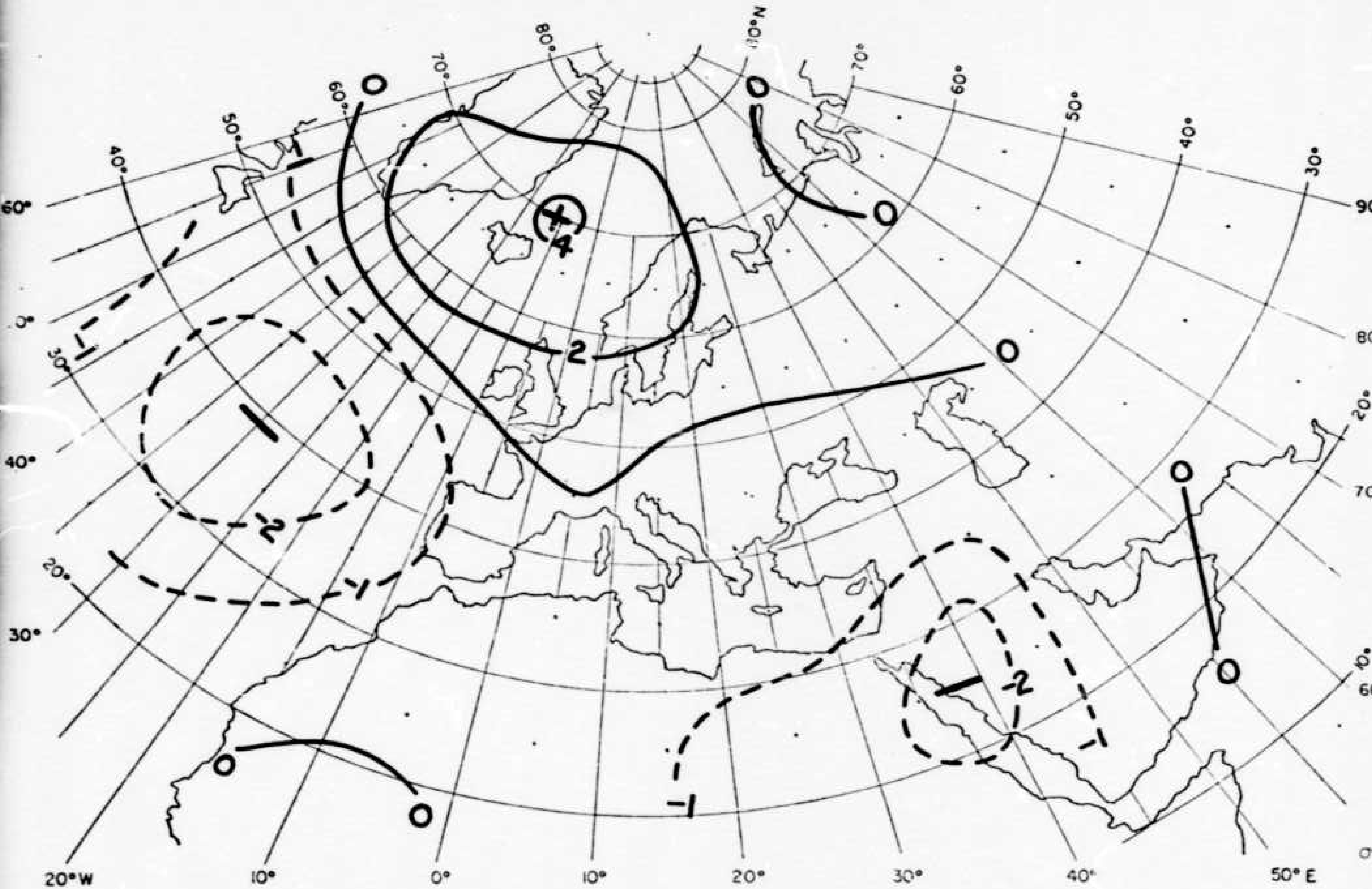

Figure 3. Difference (1960/1-1969/70 minus 1950/1-1959/60) December-February Pressure (mb).

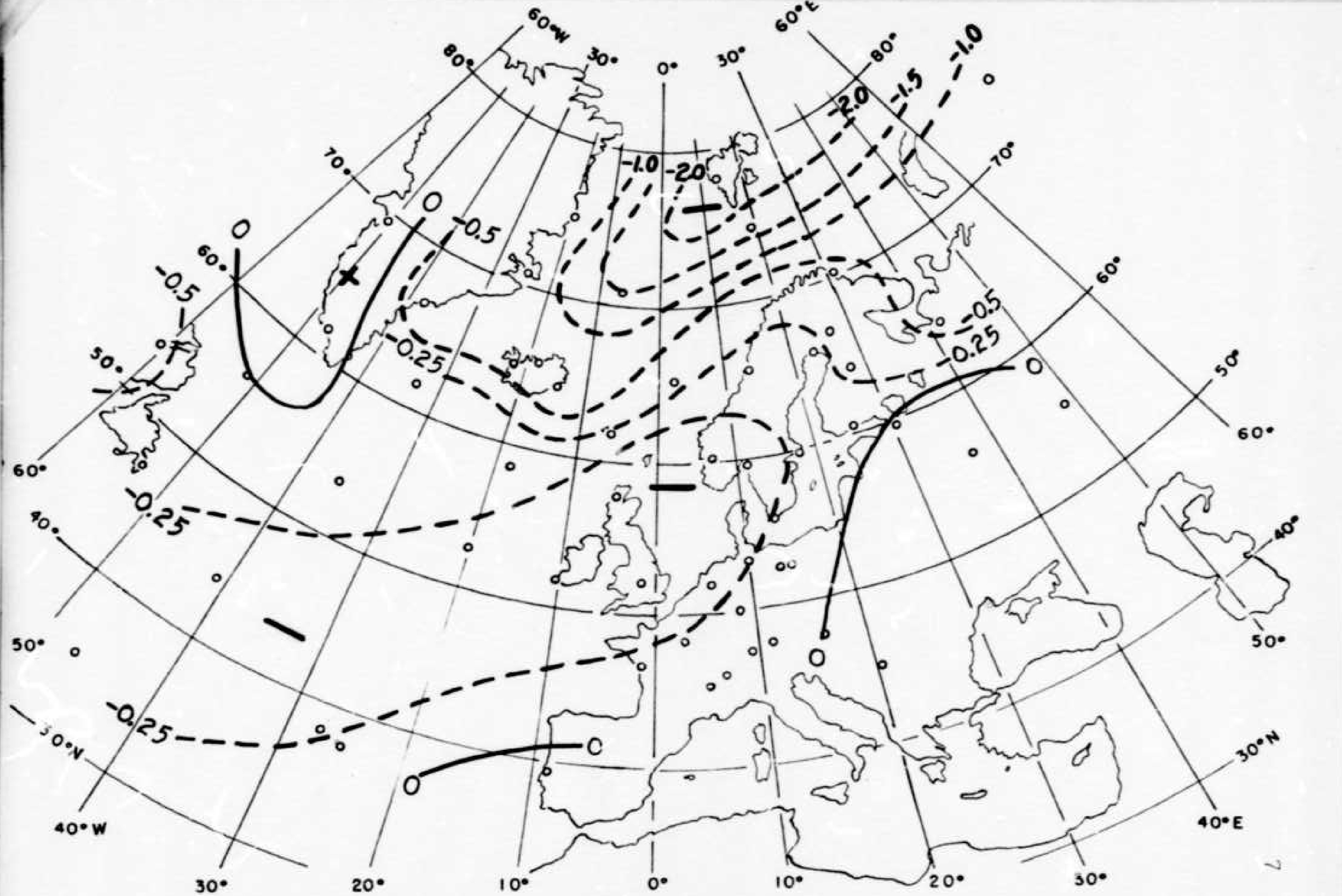

Figure 4. Differences (1961-70 minus 1951-60) mean annual air temperatures (°C). Circles denote locations of stations including OWS ships.

decade with those of the 1921-50 period (Fig. 5) show higher values (positive differences) in all but one area (B) in the 1951-60 decade than in the earlier period. The air temperatures showed a small decline (Fig. 2). The results of the comparison in the sea surface temperatures in this region between the 1951-60 and 1961-70 decades show a sharp drop (Fig. 6).

b. Western Mediterranean.

Another comparison seeking to establish a thermal lag in the ocean vis-a-vis the atmosphere was made by means of the mean January-March and July-September sea surface temperatures of the Western Mediterranean. This region in the colder half of the year is subjected to No. Atlantic storms crossing into the area by the way of the Bay of Biscay, Spain, and France, and by storms which develop locally with cold air outbreaks from the continent sweeping over the relatively warm sea. Figure 7 shows the temperature in the 1951-60 decade was higher than in the 1921-50 period while the air temperatures were declining over France, Spain and elsewhere (see Fig. 2). The fall in the mean January-March sea surface temperature in the decade 1961-70 from the previous decade (Fig. 8) would be expected to have resulted from a southward shift in storm track over the No. Atlantic (Fig. 4) and more frequent outbreaks of colder air from the continent leading in each instance to a cooling of the waters and to lower sea surface temperatures.

A similar trend as for the January-March sea surface temperatures, namely, higher July-September sea surface temperatures in the 1951-60 decade than in the 1921-50 period was found in most areas also in this quarter (Fig. 9) while the air temperatures,

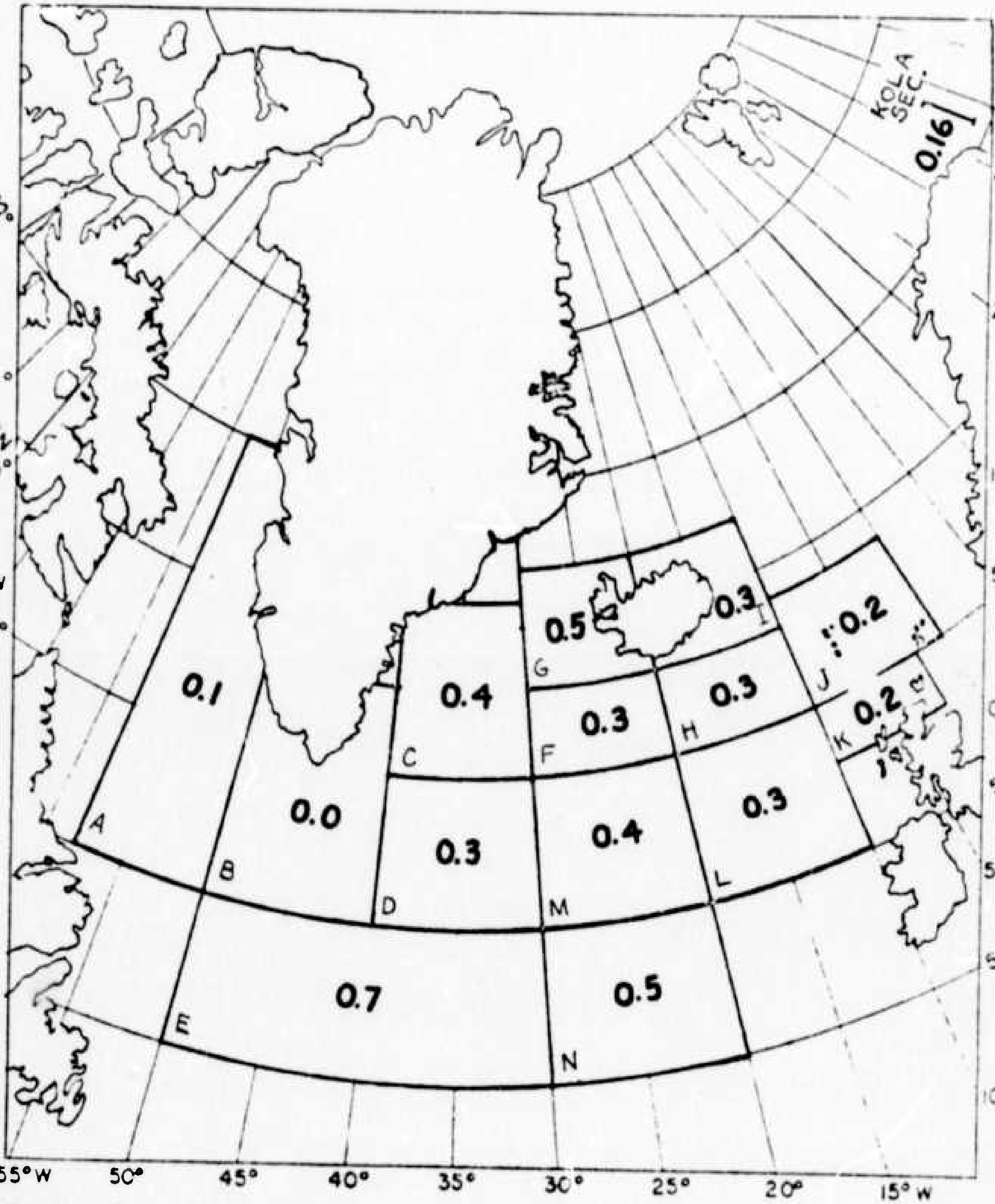

Figure 5. Differences (1951-1960 minus 1921-1950) April-September Sea Surface Temperature Areas A-N and Annual 0-200 m Sea Temperature Kola Section (°C).

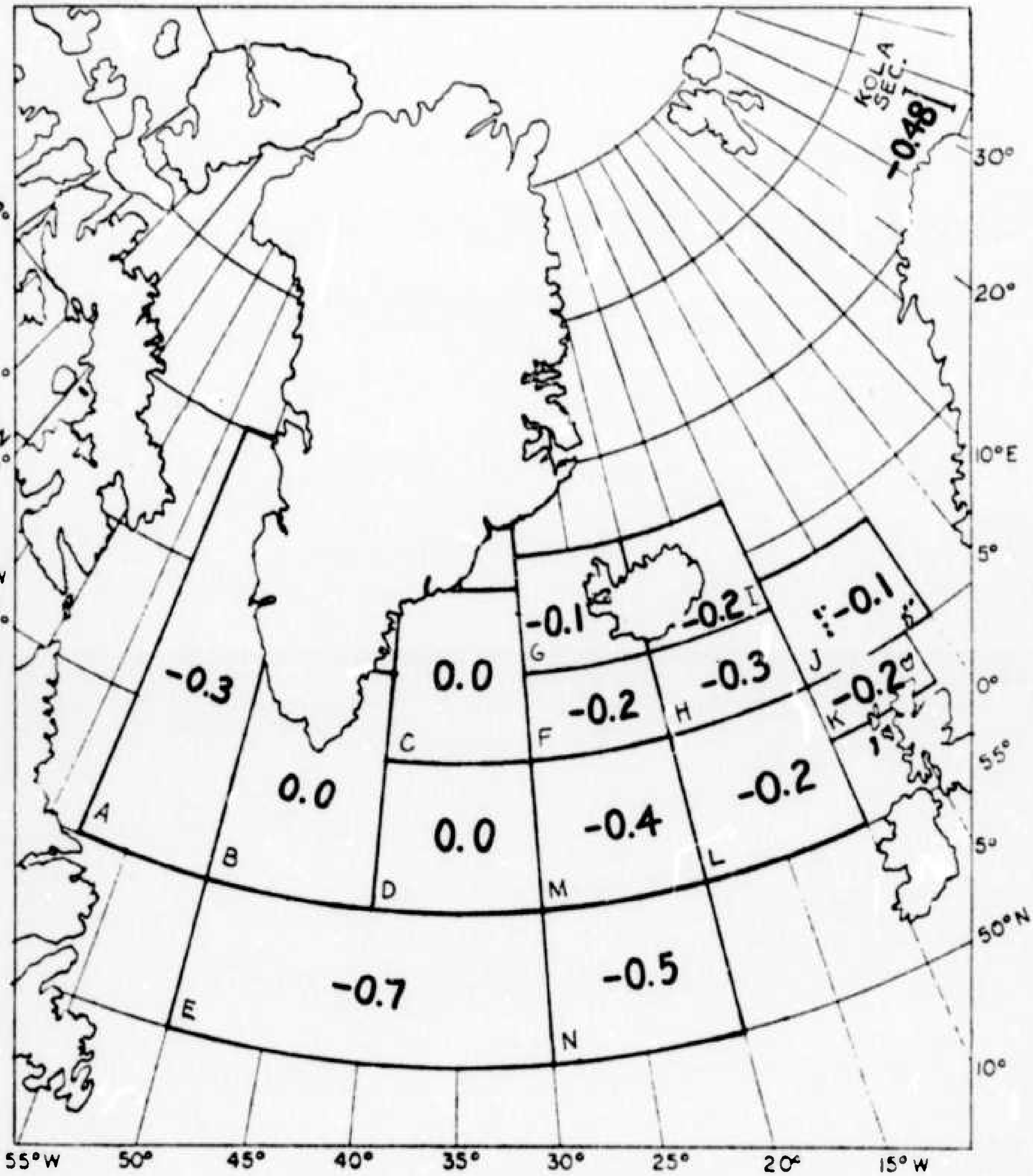

Figure 6. Differences (1961-1970 minus 1951-1960) April-September Sea Surface Temperature Areas A--N and Annual 0-200 m Sea Temperature Kola Section (^{o}C).

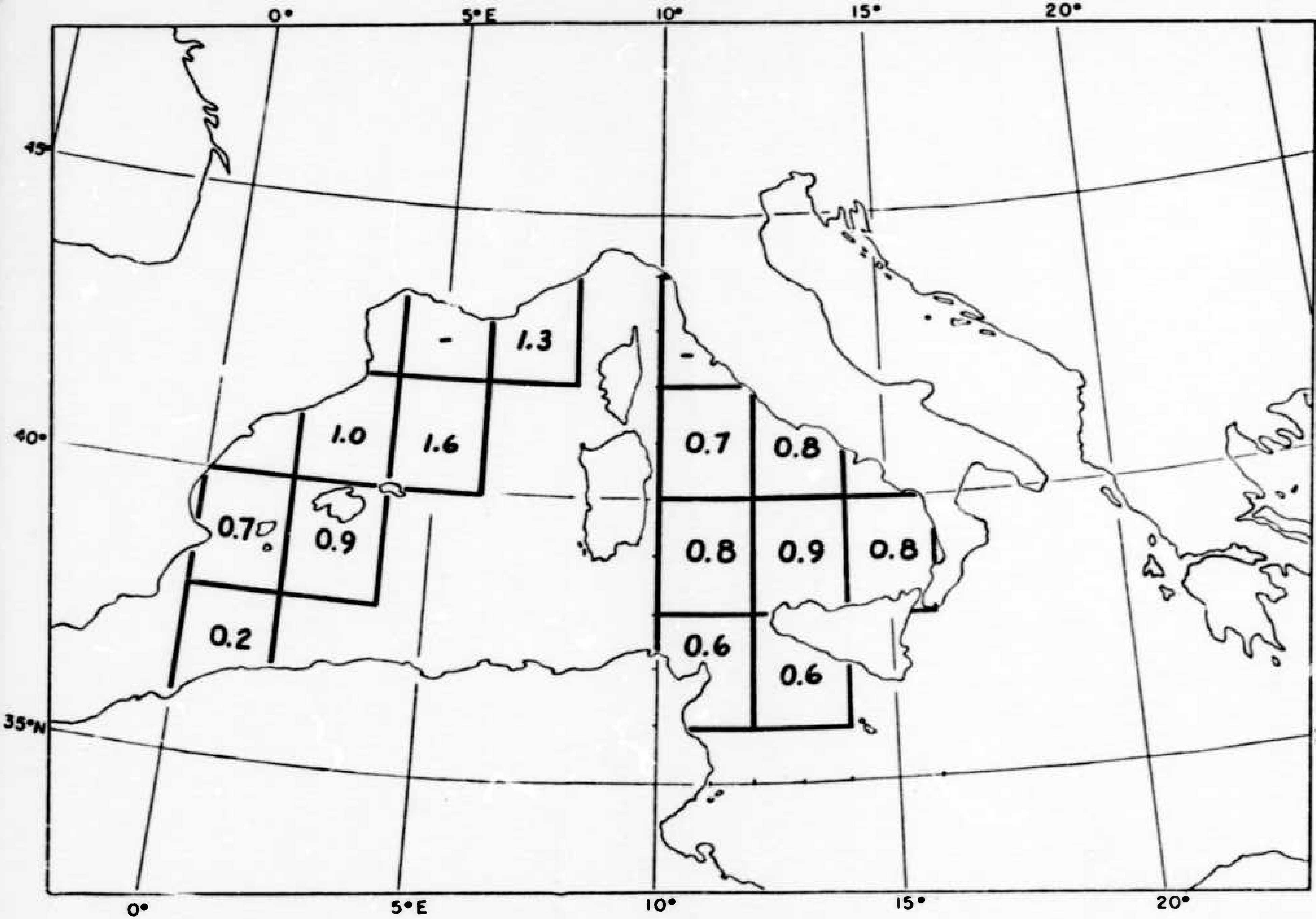

Figure 7. Difference (1951-60 minus 1921-50) January-March Sea Surface Temperature ($^{\circ}C$) in the Western Mediterranean.

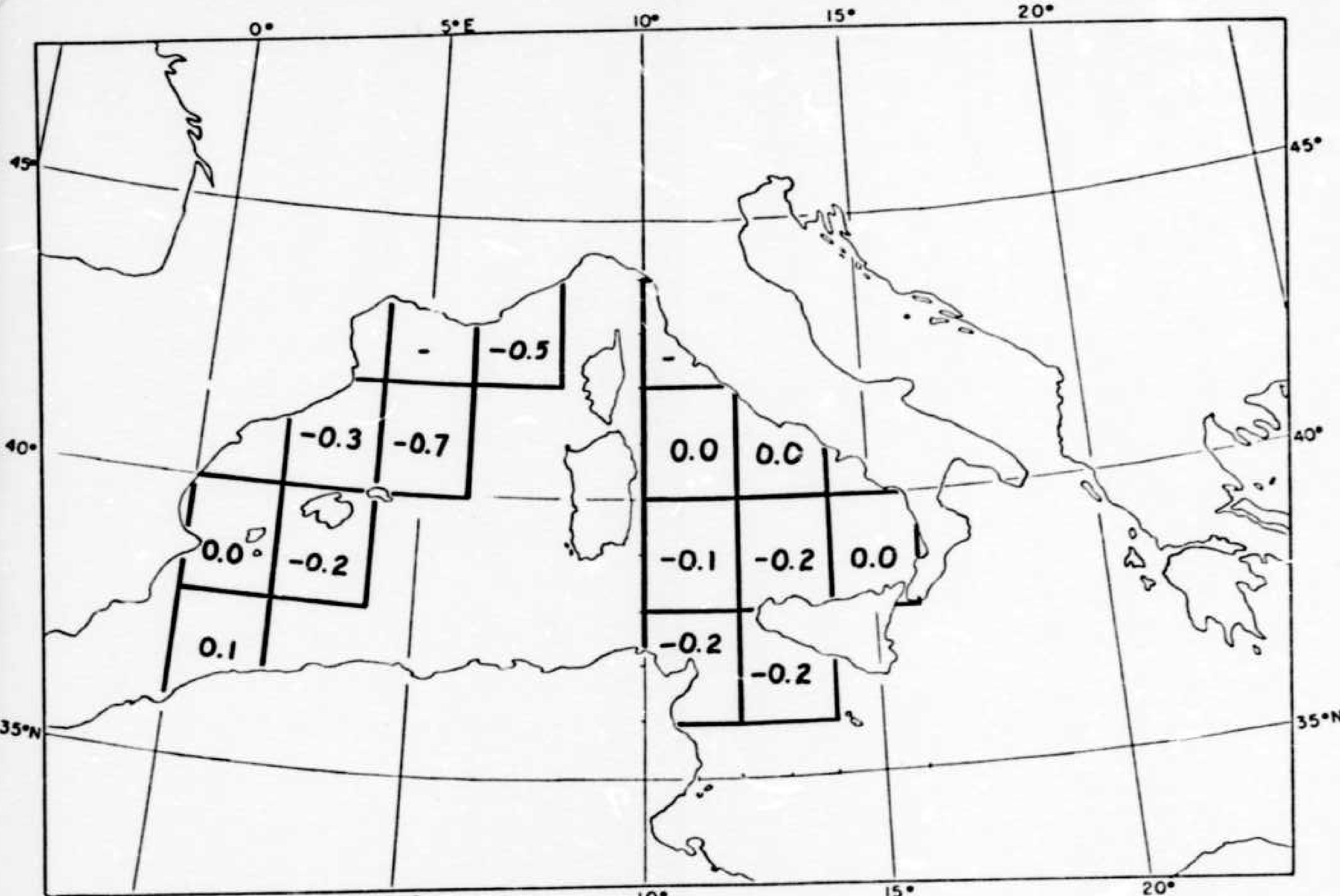

Figure 8. Difference (1961-70 minus 1951-60) January-March Sea Surface Temperature (^{o}C) in the Western Mediterranean.

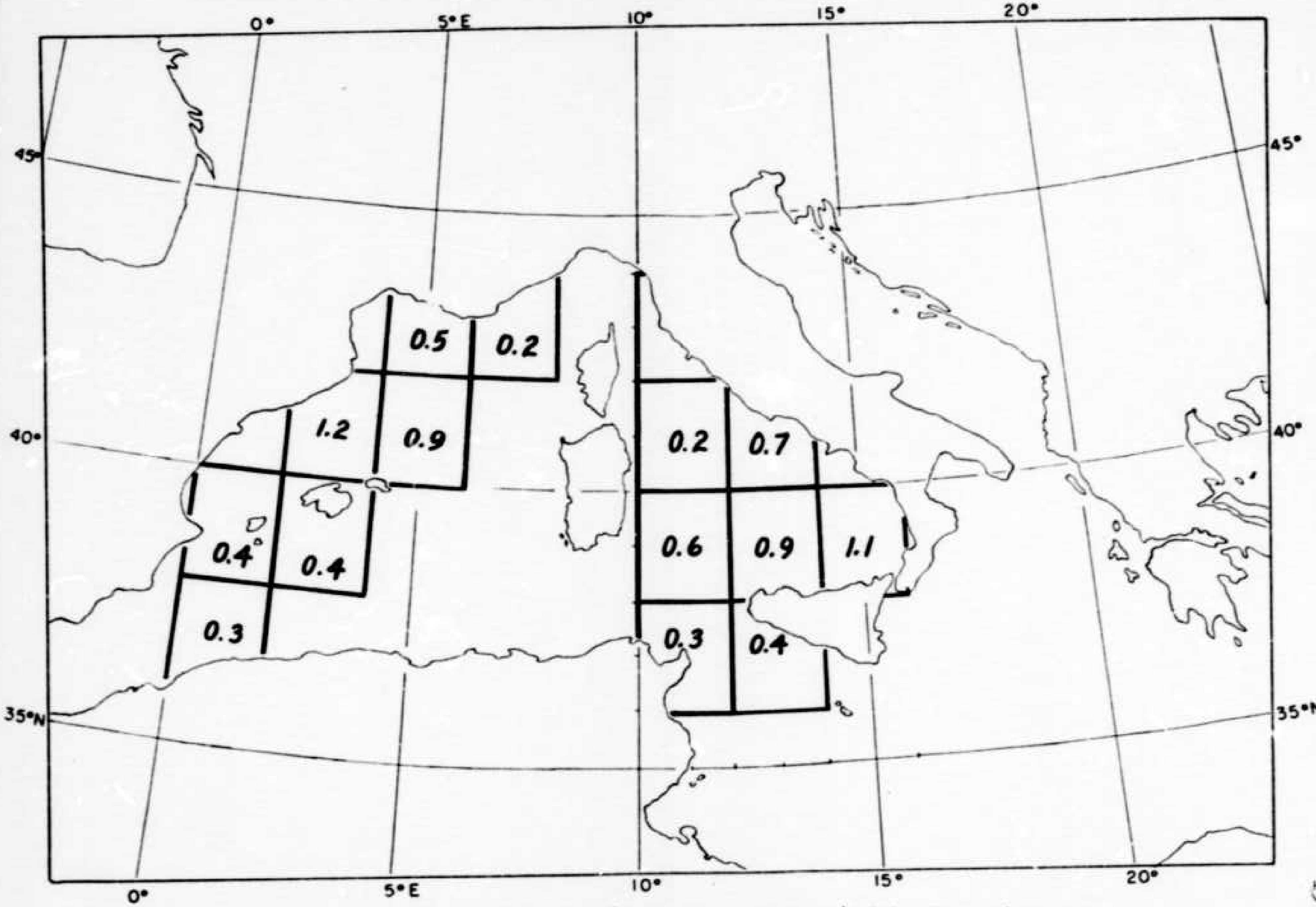

Figure 9. Differences (1951-1960 minus 1921-1950) July-September sea surface temperature (°C) Western Mediterranean.

as we have seen, showed a small decrease (Fig. 2).

One suspects that the increase in the July-September sea surface temperature in the 1951-60 decade, as well as the decrease in the 1961-70 decade from the decade which preceded it (Fig. 10) was in part due to the persistence of the temperatures anomaly in the cold season (January-March) since few if any storms cross into the western Mediterranean from the No. Atlantic in the warm half of the year.

c. <u>Kola Meridian Section Temperature (0-200 m)</u>.

Another comparison to demonstrate a possible lag in the ocean vis a vis the air was made from a consideration of the Kola Meridian Section annual temperatures in the 0-200 m layer between latitudes 70°30'N and 73°23'N along the 70°E or Kola meridian. The small increase of 0.16°C in the temperatures from the 1921-50 period to the 1951-60 decade (Fig. 5) is in keeping with the increase in the sea surface temperature in the area to the south (A-N) as is the decrease of 0.48°C in the 1961-70 decade from the 1951-60 decade, the increase in temperature in the 1951-60 decade showing a thermal lag also for the inflow of warm water into the Barents Sea.

d. <u>Ocean Weather Stations, OWS</u>.

An independent comparison of the sea surface temperatures in the northern No. Atlantic is available from the frequent observations taken at the OWS ships which began in the late 1940's. The decrease for the most part in the temperature at these stations from the 1951-60 to the 1961-70 decades (Fig. 11) corroborates the findings based on the analysis of temperatures in the areas A to N (Fig. 6).

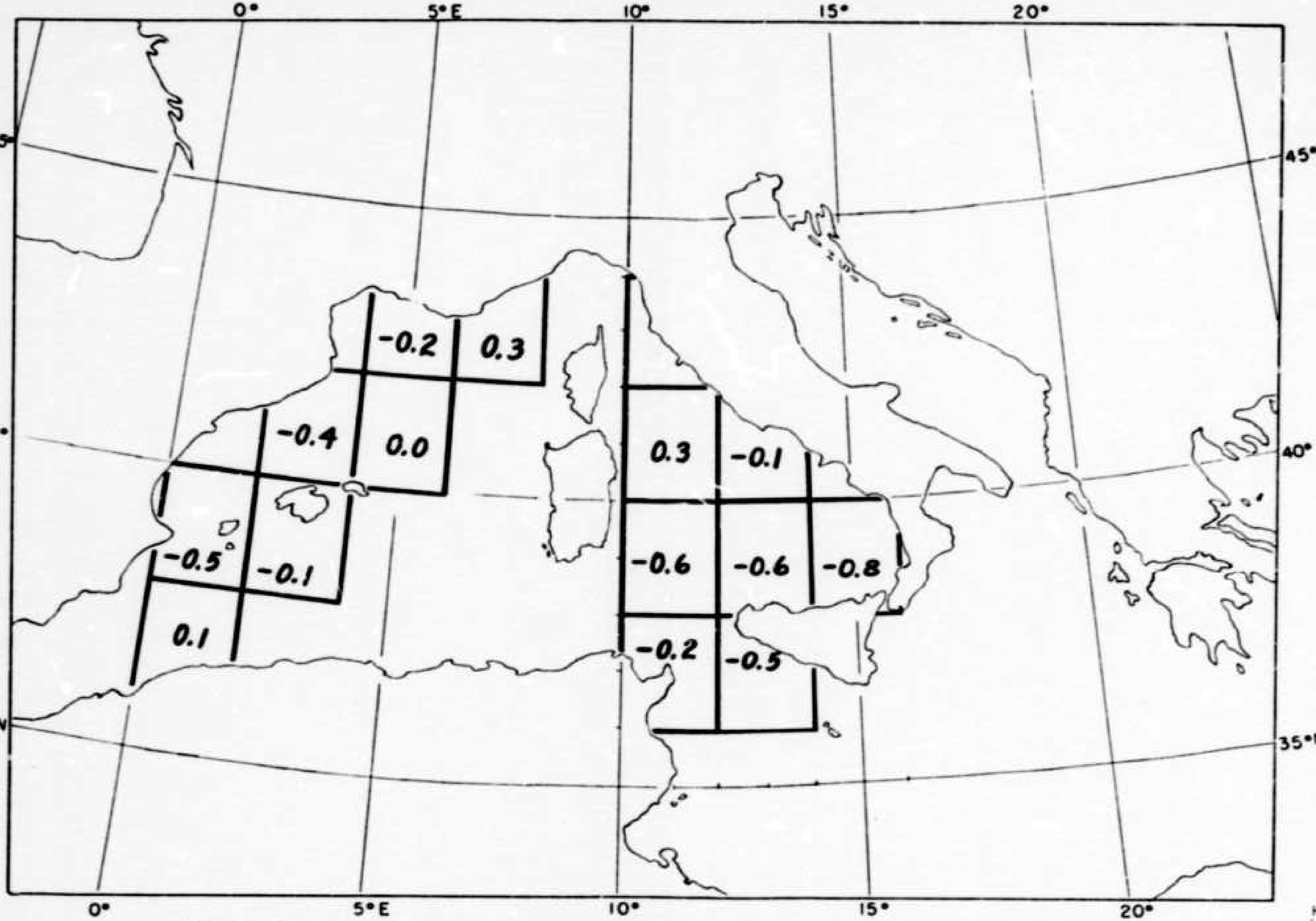

Figure 10. Differences (1961-1970 minus 1951-1960) July-September sea surface temperature (°C) Western Mediterranean.

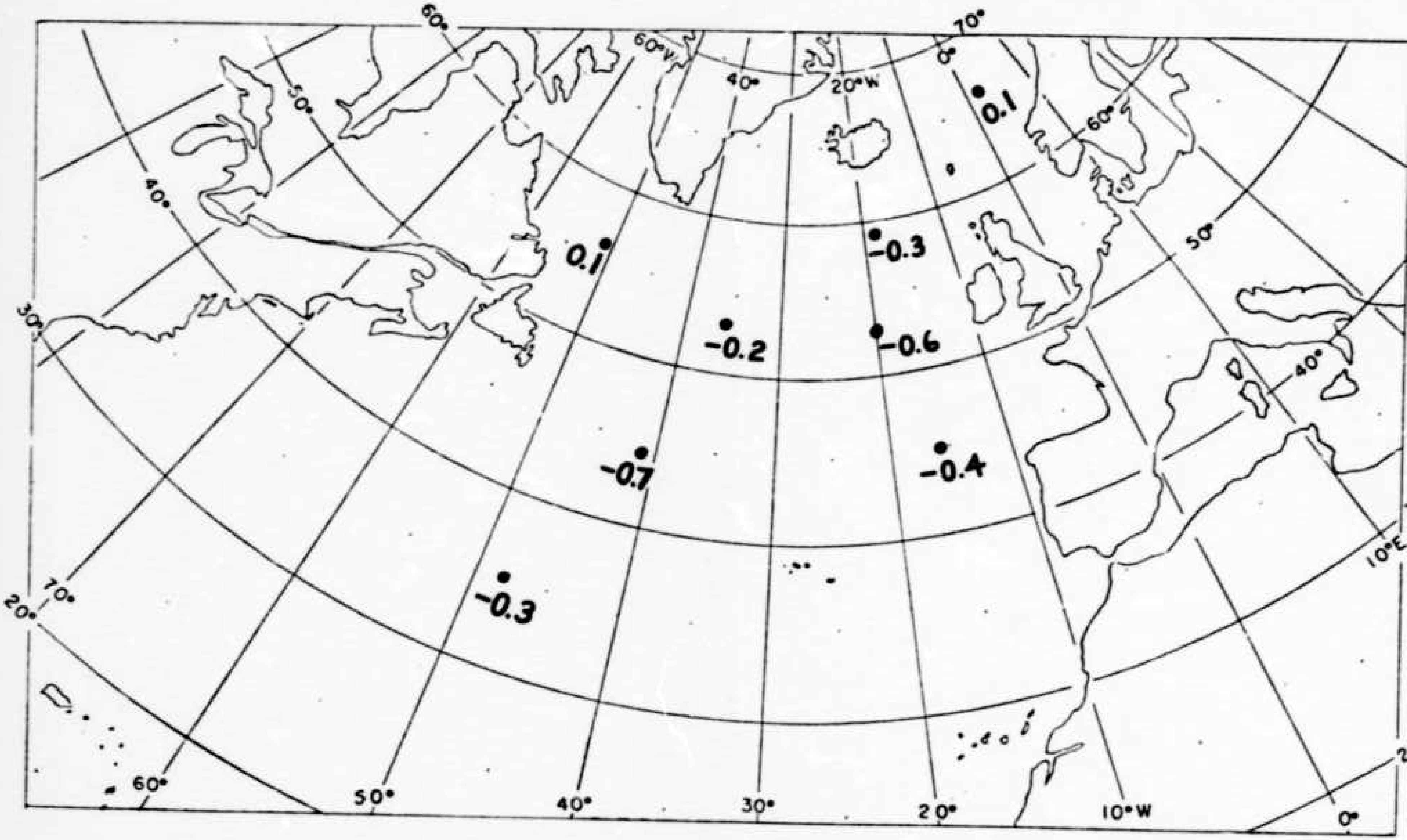

Figure 11. Differences (1961-1970 minus 1951-1960) mean annual sea surface temperature North Atlantic Ocean Weather Stations (^{o}C).

e. Ice off Iceland.

The severity of the ice off Iceland (Koch, 1945; Eythorsson and Sigtryggsson, 1971) for which data in some detail go back to the mid-18th century and in more general form to the time of settlement of Iceland, may be next considered for an analysis of a lag between the ocean and the atmosphere.

The sharp increase both in the duration and the spread of the ice along the coasts of Iceland in the 1961-70 decade over the previous decade (Fig. 12) is consistent with the greater build-up of cold air over northern Greenland and to the eastward, as well as an assumed greater frequency of northerly winds in that decade than in the earlier decades. The significant increase in the ice during this decade would be due to a marked southward transport of ice from the main pack in the north, and also to the formation of more young ice as a result of the lower air temperatures. The indicated smaller increase in northerly winds in the 1951-60 decade over the 1921-50 period than in the 1961-70 decade presumably was insufficient to produce a marked increase in the ice transport and formation of young ice.

f. No. Atlantic Weather Types (British Isles).

As further evidence of climatic changes from the 1921-50 to the 1951-60 and 1951-60 to the 1961-70 periods in the northern No. Atlantic, we investigated the trends in the frequencies of British Isles Weather Types. A decreased frequency of westerly type of circulation reflects a less zonal flow and an increased meridional type of circulation and hence lower temperatures. Thus, the average frequency of the westerly weather types (zonal flow) was 27.6% in the period 1929-49 as compared with 24.7% in

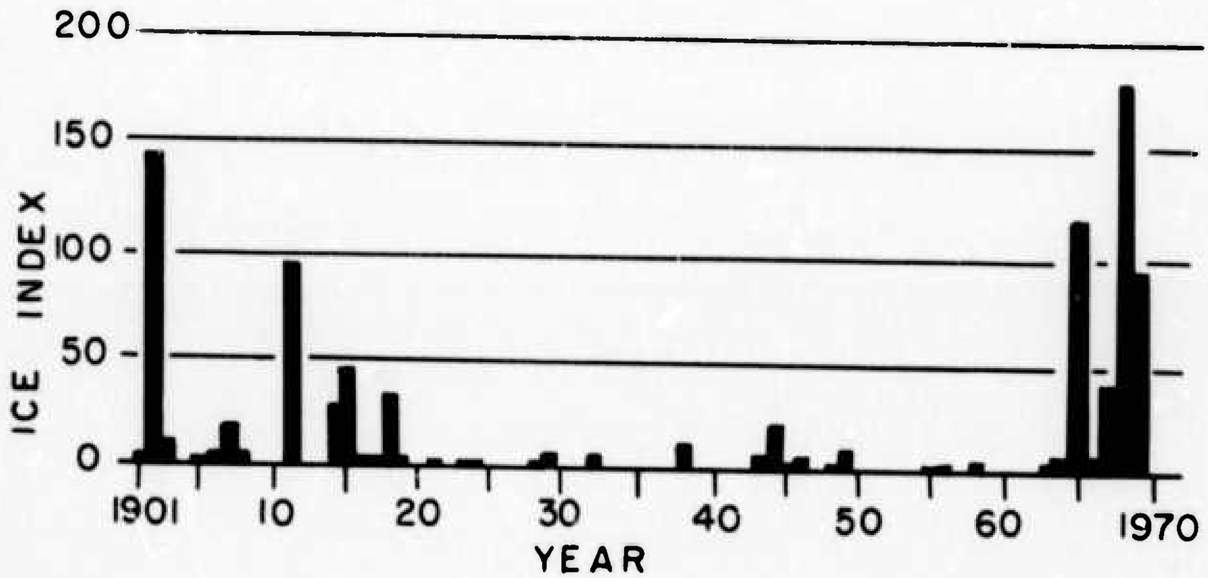

Figure 12. Ice off Iceland (duration in weeks multiplied by the number of areas with ice along the coasts). (After Koch, 1945; and Eythorsson and Sigtryggsson, 1971.)

the decade 1950-59 and only 21.9% in the following decade, 1960-69 (Lamb, 1972).

C. Data.

The data used in this study came from various sources. The mean monthly sea surface temperature deviations of the areas A-N (north of 50^{o}N) were taken from the Annal. Biol., Cons. Internl. Explor. Mer, Vols. 2-26 (1947-1970).

The sea temperatures in the layer 0-200 m along the Kola meridian were adapted from tabulation by Sleptsov-Shevlevich (1967) with those for more recent years, from the Annal. Biol., Cons. Internl. Explor. Mer, Vols. 22-26. The ice off Iceland values were taken from computations by L. Koch (1945) as extended by J. Eythorsson and H. Sigtryggsson (1971). The OWS air and sea surface temperatures were taken from Mariners Weather Log and in part were made available by the Meteorol. Office, Bracknell. Other sources were World Weather Records and Monthly Climatic Data.

In seeking to establish the thermal lag between the oceans and the atmosphere, we have limited our study to data from the open ocean since observations at coastal stations when the prevailing winds are from land, would partially reflect also the air temperatures.

D. Remarks.

Since the increase and decrease, respectively, in the annual sea temperature in the 0-200 m layer along the Kola meridian reflects largely the advection of relatively warm water into the Barents Sea from the southwest, we may conclude that the increase and decrease, respectively, in the sea surface temperature in areas A to N and at the OWS stations were also primarily the result of advection (see also Midtun, 1969). It will be noted that the decline in air temperatures in the 1950's did not reach the western mediterranean. Had this been the case, the increase in the mediterranean mean sea surface temperature might have been smaller.

The thermal lag in the ocean during the climatic change period 1921-1970 as exemplified primarily by the increase in the sea surface temperature during the 1951-60 decade while the air temperature was declining, presupposes climatic lags for other periods as well, and with longer time lags in the oceans during longer climatic or climate periods (see Emiliani, 1955).

E. Acknowledgements.

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